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LANDING CHARACTERISTICS OF AN AUTOGIRO

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SUMMARY

An investigation to determine the rate of descent, the horizontal velocity, and the attitude at contact of an autogiro in landings was made by the National Advisory Committee for Aeronautics at the request of the Bureau of Air Commerce, Department of Commerce. The investigation covered various types of landings.

The results of the investigation disclosed that the maximum rate of descent at contact with the ground (10.6 feet per second) was less than the minimum rate of descent attainable in a steady glide (15.8 feet per second); that the rates of descent at contact were of the same order of magnitude as those experienced by conventional airplanes in landings; that flared landings resulted in very low horizontal velocities at contact; and that unexpectedly high lift and drag force coefficients were developed in the latter stages of the flared landings.

INTRODUCTION

The characteristic ability of an autogiro to be landed from steep glides of approach and with very low horizontal velocities at contact with the ground has led to speculation as to the strength and shock-absorption requirements for this type of aircraft. Owing to the absence of quantitative data, the Bureau of Air Commerce, Department of Commerce, requested that tests be made to obtain representative data on autogiro landing characteristics. The essential information desired included the rates of descent, the horizontal velocities, and the attitudes of an autogiro in landings.

Tests to obtain these data were made with a Pitcairn PCA-2 autogiro, whose general characteristics are described in reference 1. The tests consisted of a series of land-

ings arranged to cover the types that would probably be made by an autogiro pilot of average, or poor, ability.

The investigation was conducted by the National Advisory Committee for Aeronautics at Langley Field, Va., during the months of May and June 1933.

APPARATUS

The PCA-2 autogiro, used for these tests, was a 2-place, open-cockpit machine equipped with a 4-blade rotor 45 feet in diameter, a fixed wing 101 square feet in area including the fuselage area between the wing roots, and a Wright 300-horsepower R-975 engine. The landing chassis was equipped with oleo-spring Aerol struts having strokes of approximately 8 inches and fitted with 8.50-10 low-pressure airplane tires. The gross weight of the autogiro as flown was approximately 2,940 pounds.

The instruments used during the tests consisted of an air-speed recorder, an accelerometer, a control-position recorder, a timer, and a recording "phototheodolite." All, except the phototheodolite, were standard N.A.C.A. instruments and were mounted in the autogiro. The recording phototheodolite, developed to record flight paths and attitudes of aircraft in flight close to the ground, is described in reference 2. The essential elements of this apparatus are a motion-picture camera, an instrument to record the azimuth and elevation angles of the camera, and a timer. The apparatus was set up approximately 800 feet from the site of the landings.

The instruments mounted in the autogiro were used to furnish histories of the air speeds, the accelerations parallel to the normal axis at and subsequent to contact with the ground, and the movements of the elevator controls. The timer furnished time indications on the records and allowed their synchronization. The records obtained with the phototheodolite were used to determine the heights of the autogiro above the ground, the rates of descent, the horizontal velocities relative to the ground, the vertical accelerations immediately prior to contact with the ground, and the attitudes at contact.

PROCEDURE

A zero time was established for synchronizing the data obtained by the instruments in the autogiro with those obtained from the phototheodolite records. This time was the instant the landing-gear wheels made contact with the ground and was determined for the instrument data by examination of the accelerometer records. The time of contact of the landing-gear wheels was determined for the phototheodolite data by noting the frame of the motion-picture photographs in which rotation of the wheels started, segments of the wheels having been painted with aluminum to make this method of identification possible.

The tests were divided into three general groups: (1) landings made by a gradual leveling-off (normal landings), (2) landings made by abruptly flaring the autogiro (flared landings), and (3) taxi and take-off runs. The air speeds of approach of the normal landings varied from that in excess of the air speed at which a three-point landing was possible to air speeds at which the elevator control felt ineffective to the pilot. The air speeds of approach for the flared landings varied from the air speed at which the autogiro gained altitude after an abrupt flare to air speeds at which the elevator control felt ineffective to the pilot. The heights of execution of the flare varied from a height relatively close to the ground to one that was deemed unsafe to exceed. The taxi and take-off runs were made over a rough portion of the landing field.

PRECISION

The estimated precision attained in the determination of the autogiro landing characteristics is:

Heights above the ground	±1/2 ft.
Horizontal (ground) velocities	±2 f.p.s.
Rates of descent	±1/2 f.p.s.
Air speeds of approach	±3 f.p.s.
Accelerations (vertical) prior to contact	±2 ft. per sec. per sec.

Accelerations (normal) at and subsequent to contact	$\pm 1/4$ g
Attitudes	$\pm 1/2^{\circ}$

Owing to the rapid change in angle of attack, the very low air speeds, and the ground effect, it was believed that the error in recording the air speed immediately prior to contact would be greater than the error in recording the air speed of approach. A comparison of the recorded air speed with the value determined by the addition of the average wind speed and the speed of the autogiro relative to the ground showed, however, that the accuracy of recording the air speed prior to contact was of the same order as that for the air speed of approach.

RESULTS AND DISCUSSION

Representative data on the landing characteristics of the PCA-2 autogiro are listed in table I and plotted in figures 1 and 2. The data show that the landings which may be classified as being those made by an autogiro pilot of average ability (landings made from air speeds of approach relatively close to the air speed that allowed a gentle and relatively slow landing and in which the leveling-off or the flaring was executed within 8 feet of the ground) resulted in rates of descent at contact of less than 6 feet per second. Landings in which poor ability was simulated, i.e., landings which did not fall within the ranges mentioned above, resulted in rates of descent at contact that approached a value of 11 feet per second. These latter rates of descent, even for the worst landing, were less than the minimum rate of descent in the steady glides with the propeller stopped (15.8 feet per second, fig. 1).

The maximum rate of descent at contact (10.6 feet per second at the center of gravity) occurred in flared landing 12. In this landing the air speed of approach was sufficient to provide definite response to the elevator movements. The flare was started at a height of approximately 14 feet with an air speed of 55 feet per second and resulted in an air speed at contact of 23 feet per second with a small negative horizontal velocity component relative to the ground. The severity of the landing resulted in failure of the tail skid and subsequent damage to the rudder.

Figure 2 is a plot of the rate of descent at contact against the height above the ground at which the execution of leveling-off or flaring was started for the normal and the flared landings, respectively. It is interesting to note that, with one exception, the rate of descent at contact appears to depend primarily on the height above the ground at which leveling-off or flaring was started. In the exception (landing 5) the air speed of approach was higher than that of the other landings represented on the figure and the direction of the elevator movement was reversed twice between the start of the leveling-off and contact with the ground. Figure 2 further shows that no marked difference in the rates of descent at contact occurred for the two types of landings. It should also be noted that the rates of descent at contact are approximately of the same relative order of magnitude as would be experienced by the conventional airplane.

In general, there was an appreciable difference in the horizontal velocity at contact for the normal and the flared types of landing (table I). In the flared landings, a very marked reduction occurred in the horizontal velocity during the execution of the flare, the reduction being so great that in a wind of moderate intensity the horizontal velocity relative to the ground at contact was practically zero. Owing to the large reduction in horizontal velocity that may be realized in the flared landing, the autogiro has an appreciably wider range of horizontal velocities at contact than the conventional airplane.

The vertical accelerations experienced immediately prior to contact with the ground varied from -4 feet per second per second (-0.12g) to 5 feet per second per second (0.15g) which shows a variance of the vertical component of the aerodynamic forces existent at contact from approximately 88 percent to 115 percent of the gross weight of the autogiro. No means were available for determining the magnitude of this component existent at the end of the contraction stroke of the shock-absorbing units. An indication of the magnitude of this component generated by the rotor was obtained, however, by noting the rotor coning angle as recorded by the camera. In all but one of the landings, the coning angle remained positive during and for a short period of the time following the completion of the initial contraction-stroke cycle of the shock-absorbing units. In the remaining landing, the coning angle was approximately zero at the end of the cycle and became negative shortly after.

The zero coning angle existent at the completion of the initial shock-absorber contraction cycle indicates that in one landing the rotor thrust was less than the weight of the rotor blades, which were approximately 11 percent of the gross weight of the autogiro. The vertical component of the aerodynamic forces had thus dropped to as low as approximately 11 percent of the gross weight of the autogiro during the cycle. It therefore appears that during the absorption of the vertical component of the autogiro's kinetic energy at contact with the ground practically the entire support of the autogiro may be transferred from the aerodynamic forces to the landing gear. Such a transfer requires that the shock-absorbing system absorb not only the vertical component of the contact kinetic energy but also absorb a portion of the change in potential energy represented by the vertical displacement of the autogiro during the initial shock-absorber contraction stroke and, in addition, offer a resisting force approximately equal to the weight of the autogiro at the end of the cycle.

The rotor speeds varied from 129 r.p.m. to 136 r.p.m. during the landings (table I). The rotor speeds were sensibly constant, however, during the recorded portions of each of the landings. The recorded portions, in general, included the last stage of the approach glide, the leveling-off or flaring, and the final approach onto the ground.

The rotor speed characteristics prevailing during the landings are different than would be expected from those indicated by previous flight tests. During the accelerated-flight tests (reference 3) a rapid increase in rotor speed accompanied an increase in normal force on the rotor. In the landings, rotor speeds remained sensibly constant even though in some of the flared landings the normal force on the rotor was substantially increased. The decrease in air speeds that occurred during the landings would not cause a change in rotor speeds as the tip-speed ratios (0.1 to 0.2) prevailing during the landings were in the range of constant rotor speeds for the condition of constant normal force.

Another surprising difference between landing and normal-flight characteristics is the high force coefficients developed at contact (fig. 3). The lift and drag coefficients determined from the normal landings were but slightly greater than those determined from steady glide tests, whereas, those from the flared landings were appre-

ciably greater than the maximum realized in steady glides. The force coefficients deduced to be existent immediately prior to contact in the landings are but approximate in magnitude owing to the use of the insufficiently precise horizontal and vertical accelerations determined from the phototheodolite data and to the assumption of constant gross weight of the autogiro. The calculated coefficients, however, are believed to be sufficiently accurate to permit the qualitative comparison.

The reasons for the constant rotor speeds during the accelerated portions of the landing approaches and the unexpectedly high force coefficients prevailing during the flared landings are impossible to explain owing to lack of development of autogiro theory covering accelerated flight and the influence of ground effect on the effective angle of attack. It is believed, however, that a major contributing factor toward the high force coefficients is a relatively large ground effect at the large angles of attack and low air speeds attained in the abruptly flared landings.

CONCLUSIONS

1. The maximum rate of descent of the autogiro at contact with the ground was 10.6 feet per second.

2. When the landings were made from approximately the same air speed of approach, no marked difference occurred in the rate of descent at contact for the normal or the flared landing, the rate of descent at contact being roughly a function of the height above the ground at which the execution of the leveling-off or the flaring was started.

3. The horizontal velocities with which an autogiro may be landed cover a wide range; the horizontal velocities at contact with the ground in flared landings are, in general, very low.

4. The lift and drag coefficients developed during the flared landings were appreciably greater than the maximums realized in steady glides.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., October 4, 1934.

REFERENCES

1. Wheatley, John B.: Lift and Drag Characteristics and Gliding Performance of an Autogiro as Determined in Flight. T.R. No. 434, N.A.C.A., 1932.

2. Thompson, F. L., Peck, W. C., and Beard, A. P.: Air Conditions Close to the Ground and the Effect on Airplane Landings. T.R. No. 489, N.A.C.A., 1934.

3. Wheatley, John B.: Wing Pressure Distribution and Rotor-Blade Motion of an Autogiro as Determined in Flight. T.R. No. 475, N.A.C.A., 1933.

TABLE I. RESULTS OF PCA-2 AUTOGIRO LANDING INVESTIGATION

Number of landing	Type of landing	Start of elevator movement		Velocities at contact with the ground				Rates of descent at contact		Attitude at contact	Vertical accelerations					Rotor speed			Length of record	Remarks
					Horizontal						Immediately prior to contact	Contact		Maximum after contact		One second prior to contact	At contact	Average over record		
		Air speed[a]	Altitude	Air speed[a]	Ground	Air[a]	Wind[b]	c.g.	Tail		c.g.	c.g.	Tail	c.g.	Tail					
		feet per sec.	ft.	feet per sec.	feet per sec.	feet per sec.	feet per sec.	feet per sec.	feet per sec.	deg.	feet per sec.[2]	g	g	g	g	r.p.m.	r.p.m.	r.p.m.	second	
1	Normal	54	4 1/2	42	35	42	6	4.0	4.6	13.4	-4	1.6	1.8	1.6	2.2	134	134	134	2.35	
2	"	-	-	41	37	41	6	3.6	4.7	15.4	0	1.5	1.7	1.4	1.8	131	131	131	1.37	Gradual leveling-off.
3	"	53	5	46	43	46	2	3.4	3.4	13.6	1	1.5	1.8	1.5	1.6	130	130	130	3.05	
4	"	52	2 1/2	44	43	44	2	2.7	3.6	13.4	0	1.4	1.6	1.6	1.6	132	132	133	4.34	Pancaked from 2 feet.
5	"	57	14 1/2	40	35	40	4	2.8	2.9	16.3	2	1.4	1.8	1.5	1.8	130	130	130	1.25	No sharp change in flight path.
6	"	51	13	37	32	36	4	8.3	9.8	12.2	0	2.3	1.4	1.6	2.6	129	129	129	1.03	Response to elevator poor.
7	Flared	51	1/2	38	26	38	12	1.6	1.3	14.7	-4	1.4	1.4	1.4	2.1	132	132	132	.91	
8	"	53	6 1/2	36	26	36	12	4.3	5.6	15.5	0	1.5	2.1	1.4	1.6	133	133	133	2.25	Response to controls poor.
9	"	48	9 1/2	27	10	26	12	8.3	7.5	15.1	-	2.7	2.7	1.6	1.8	135	135	135	3.33	Pancaked from 9 feet.
10	"	63	-	33	0	33	20	4.7	5.3	15.4	-1	1.4	1.9	-	-	136	134	136	2.44	Controls effective; dropped in from 4 feet.
11	"	50	13	25	0	23	20	9.2	8.3	17.3	-1	2.5	2.7	-	-	129	133	134	3.37	Elevator control "soft."
12	"	55	14	23	-.2	20	20	10.6	10.2	18.1	-1	2.3	2.6	-	-	133	133	134	3.15	Tail skid broke.
13	"	53	-	-	53	-	-	2.7	4.8	17.3	-	1.6	2.2	1.7	2.3	-	-	-	-	
14	"	63	1	29	14	29	-	4.4	6.7	14.7	-	2.3	2.2	2.0	2.2	132	132	131	3.78	Flared at 1 foot, rose to 5 1/2 feet and pancaked.
15	"	52	8	43	39	43	4	3.0	6.6	16.2	4	1.6	2.3	2.0	2.2	-	-	-	-	Poor response to elevator.
16	"	44	-	41	35	40	4	10.4	7.4	8.8	5	2.9	2.1	2.1	2.8	-	-	-	-	No appreciable response to elevator; hit hard.
17	"	48	-	43	29	42	-	7.0	12.0	12.8	-	2.8	-	1.6	-	-	-	-	-	Elevator ineffective; hit hard.
	Taxi	-	-	-	-	-	-	-	-	-	-	-	-	1.7	1.8	-	-	-	-	Slow taxi over rough field.
	Take-off	-	-	-	-	-	-	-	-	-	-	-	-	1.8	1.4	-	-	-	-	Long take-off run.

[a]Indicated air speed, approximately true value.

[b]Wind speeds are approximate values obtained from local meteorological station.

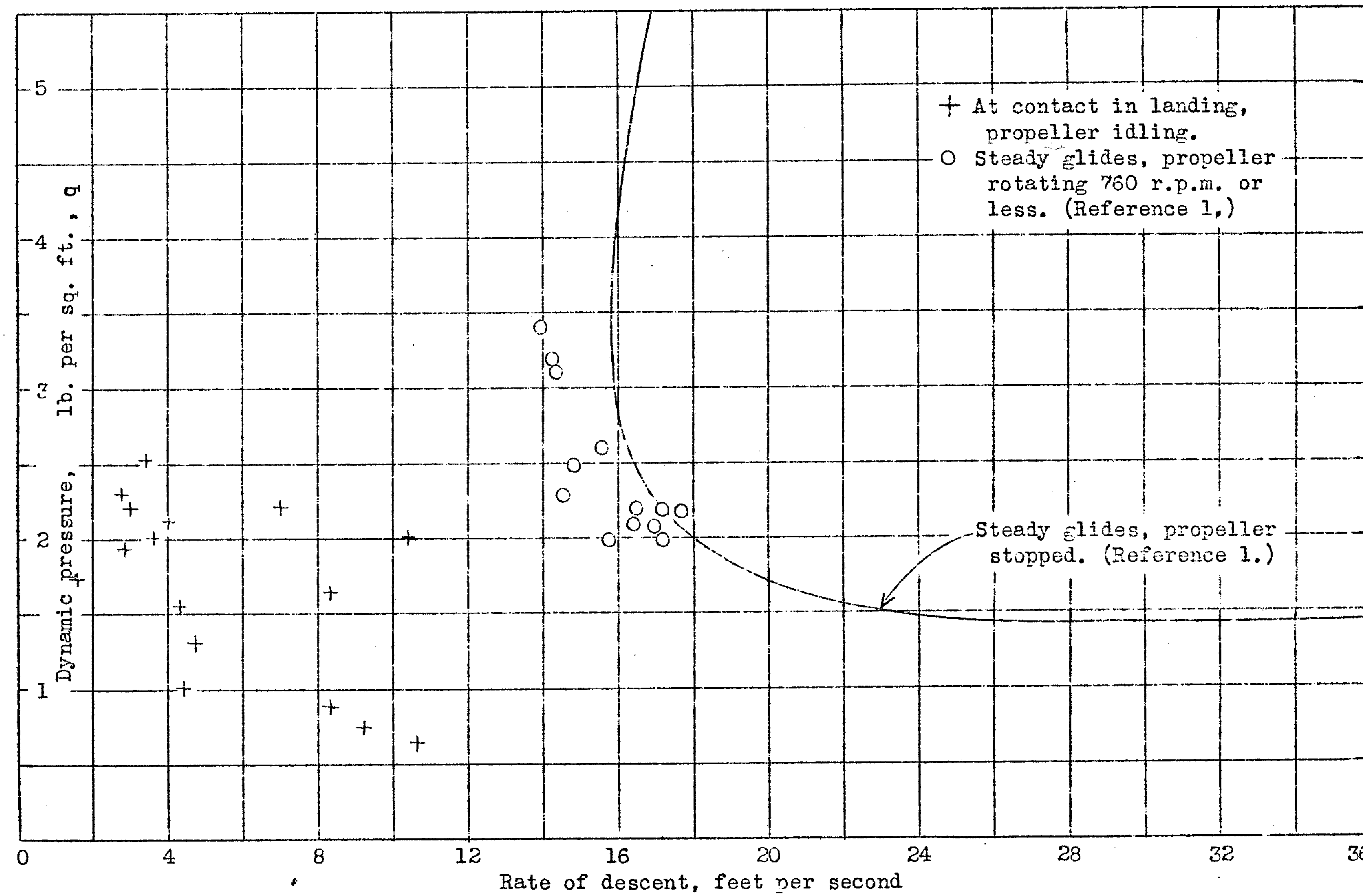

Figure 1.-Variation of rate of descent of a PCA-2 autogiro with dynamic pressure.

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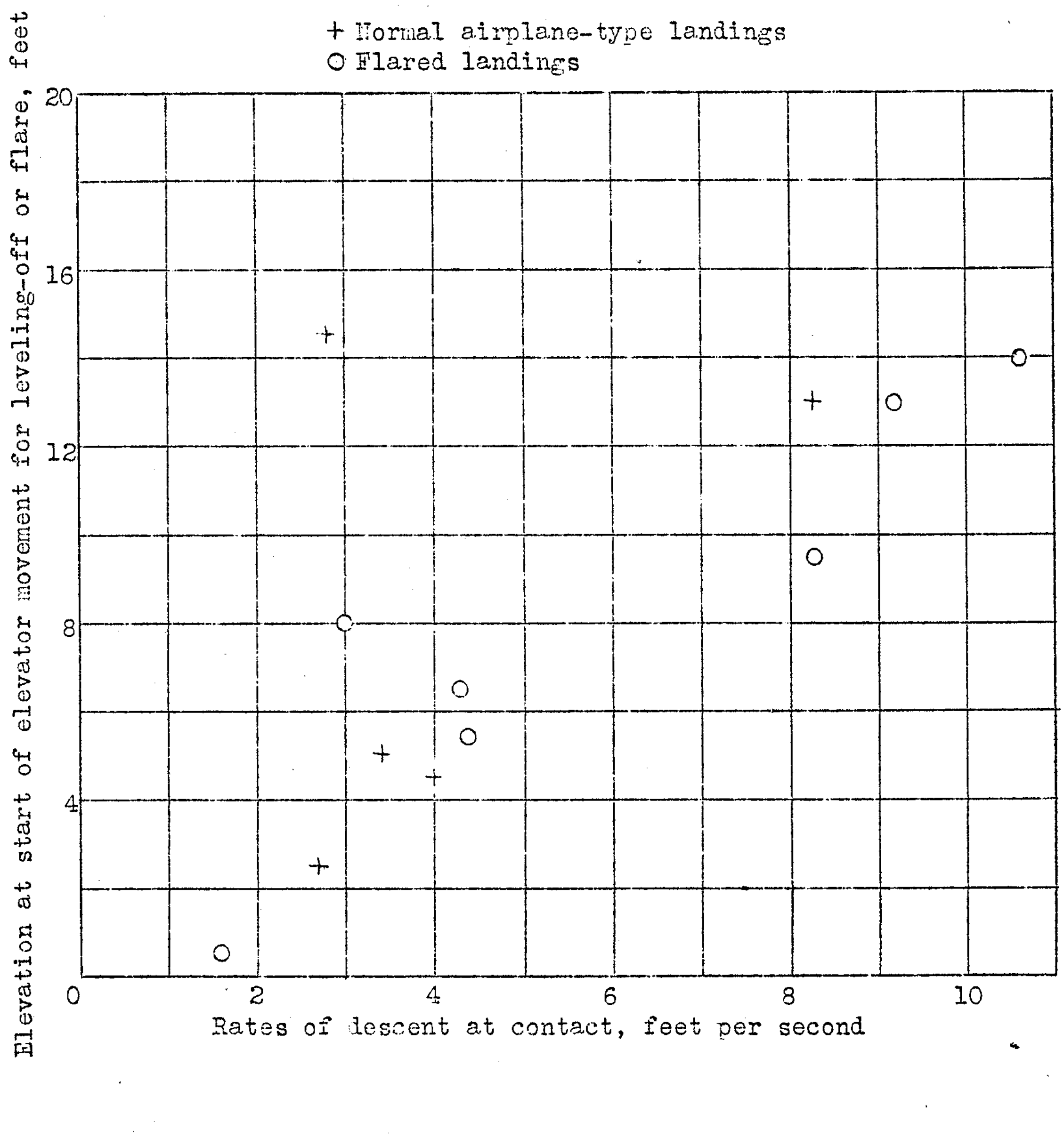

Figure 2.-Rates of descent at contact in autogiro landings.

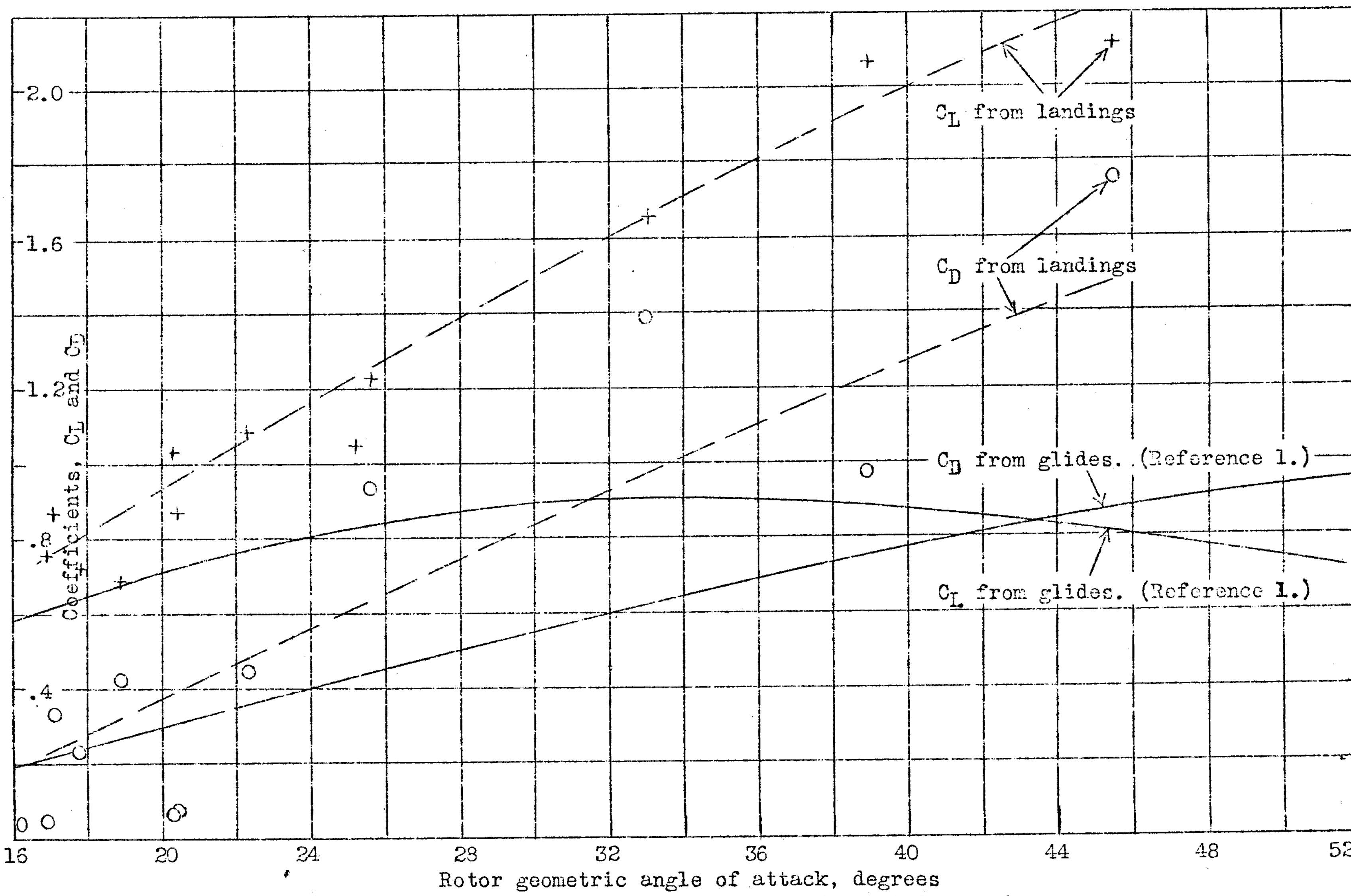

Figure 3.-Lift and drag coefficients of a PCA-2 autogiro.

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